Role of binder, permeability-reducing admixtures and cracking in the watertightness of concrete structures

A thesis by

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CERTIFICATE OF ORIGINAL AUTHORSHIP

I certify that the work in this thesis has not previously been submitted for a degree nor has it been submitted as part of requirements for a degree except fully acknowledged within the text.

I also certify that the thesis has been written by me. Any help that I have received in my research work and the preparation of the thesis itself has been acknowledged. In addition, I certify that all information sources and literature used are indicated in the thesis.

Mohammadreza Hassani Esgandani

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Date:

Sincerely Dedicated to

My Mother and Father

Fatemeh and Ebrahim

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LIST OF PUBLICATIONS BASED ON THIS RESEARCH

- Hassani, M., Vessalas, K., Baweja, D. & Schmidt, Z. 2013, 'Assessment of watertight concrete and role of chemical admixtures', *Concrete Institute of Australia's Biennial National Conference*, Gold Coast, Australia.
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NOMENCLATURE

A	Area
a	Absorption rate
c	Mass concentration
D	Coefficient if ionic diffusion
d	Depth of penetration
D	Thickness
D_0	Maximum diffusion coefficient (at infinite temperature)
E	Modulus of elasticity
F	Mass flux
f_c'	Characteristic compressive strength of concrete
f_{ct}	Tensile strength of concrete
F_u	Ultimate compressive strength
g	Gravitational acceleration
h	Water head
K	Coefficient of water permeability (cracked and uncracked material)
k'	Coefficient of intrinsic water permeability (cracked and uncracked material)
kO	Coefficient of oxygen permeability
K_s	Coefficient of water permeability of single crack
kT	Coefficient of Torrent permeability
L	Length
m	Mass
N	Quantity
P	Pressure
P	Volumetric porosity
p_w	Pore water pressure

Q	Flow rate
R	Radius
S	Sorptivity
S_r	Crack spacing
t	Time
V	Volume
v	Velocity
W	Weight
w	Crack width
x	Distance
z	Elevation
ε	Strain
Δ	Spacing
η	Viscosity
ρ	Density
σ	Stress
ν	Porosity
ζ	Reduction factor

ABBREVIATIONS

ACI	American Concrete Institute
AS	Australian Standard
AWWA	American Water Works Association
BS	British Standard
CAE	Complete Abaqus Environment
COD	Crack Opening Displacement
CP	Crystalline Permeability-reducing Admixture
C-S-H	Calcium Silicate Hydrate
FA	Fly Ash
FE	Finite Element
FEA	Finite Element Analysis
FRC	Fiber Reinforced Concrete
FTIR	Fourier-Transform Infrared Spectroscopy
GGBFS	Grand Granulated Blast-Furnace Slag
GP	General Purpose Cement
HCP	Hardened Cement Paste
HP	Hydrophobic Permeability-reducing Admixture
ISA	Initial Surface Absorption
ISAT	Initial Surface Absorption Test
ITZ	Interfacial Transition Zone
IUPAC	International Union of Pure and Applied Chemistry
LVDT	Linear Variable Differential Transformer
NA	Not Applicable
OPC	Ordinary Portland Cement
PFA	Pulverised Fly Ash
PRA	Permeability-Reducing Admixture

PRAH	Permeability-Reducing Admixture for Hydrostatic Conditions
PRAN	Permeability-Reducing Admixture for Nonhydrostatic Conditions
PSD	Particle Size Distribution
NTS	Not to Scale
RC	Reinforced Concrete
RH	Relative Humidity
SAI	Strength Activity Index
SCM	Supplementary Cementitious Materials
TPT	Torrent Permeability Test
UPV	Ultrasonic Pulse Velocity
w/b ratio	Water to binder ratio
w/c ratio	Water to cement ratio
WR	Water Reducer Admixture
WT	Weight
XRD	X-ray Diffraction
XRF	X-ray Fluorescence

ABSTRACT

In the absence of other deterioration mechanisms, concrete structures can be deemed to be durable and serviceable when they resist water penetration and perform their function with minimal maintenance during their service life. Watertightness of in-service concrete structures is assessed by evaluating the water penetration properties of the concrete. The main sources of water penetration in a concrete structure may arise from the concrete matrix and the presence of cracks, joints and construction defects in the concrete elements. In this study, the water penetration through the uncracked and cracked concrete matrices is investigated.

The water penetration through the uncracked concrete matrix is influenced by different parameters such as mix constitutions including the addition of the chemical admixtures, and the placing and curing conditions of the concrete. The popularity of permeability-reducing admixtures (PRAs) in producing watertight concrete has increased significantly in the last couple of decades due to their cost and time efficiency compared to the application of membrane-based waterproofers. However, the available information with regard to their performance has not been expanded at the same pace, so the reliance is mostly based on the manufacturer's data associated with experimental evidence. This study aims to evaluate the effect of common PRAs as well as the binder type, binder content, w/b ratio and maturity of the concrete on the absorption and permeability properties of the concrete. The study undertaken includes experimental research and statistical analyses to reveal the influence of the aforementioned factors and their significance. Results indicate that although the PRAs were beneficial in certain cases, the effect of binder characteristics such as binder content, binder type and w/b ratio was more pronounced than the effect of the PRAs. The efficiency of the PRAs was found to be a function of the w/b ratio, binder type and the type of test method used to evaluate water penetration.

From a design perspective, water penetration in concrete structural elements mainly results from the presence of cracks that increase water penetration by several orders

of magnitude when compared with the uncracked concrete matrix. In the current study, the effect of cracking on the water penetration properties of concrete was investigated experimentally and numerically. Controlled cracks with predefined widths of 0.1 mm to 0.4 mm were induced in concrete specimens through feedback-controlled splitting tensile tests. The permeability characteristics of cracked concrete specimens were determined and compared with those of uncracked concrete specimens. Crack healing was investigated over time in concretes with and without PRA additions. Numerical relationships were developed between crack width and water penetration. Results indicate that the water penetration in the cracked concrete is largely influenced by the crack size and geometry, and the flow rate is cubically related to the crack width. The induced cracks in all types of concrete evaluated were found to heal under the conditions examined when these crack widths were below 0.1 mm. The cracks in concretes containing crystalline PRAs were found to heal at widths of up to 0.2 mm.

To predict the water penetration in concrete structures, finite element analysis was employed to model the permeability of cracked concrete under service loads. The permeability of the concrete specimens was modelled and validated against the experimental results. Subsequently, two common types of watertight concrete structures including a roof slab and a rectangular water tank were analysed. The areas in these concrete structures with high potential for water penetration due to cracking (before and after self-healing) were predicted via finite element models. Results were in agreement with the experimental test data carried on the cracked concrete specimens.